

Liquid Oxygen Propellant Densification Unit Ground Tested With a Large-Scale Flight-Weight Tank for the X-33 Reusable Launch Vehicle

Propellant densification has been identified as a critical technology in the development of single-stage-to-orbit reusable launch vehicles. Technology to create supercooled high-density liquid oxygen (LO₂) and liquid hydrogen (LH₂) is a key means to lowering launch vehicle costs. The densification of cryogenic propellants through subcooling allows 8 to 10 percent more propellant mass to be stored in a given unit volume, thereby improving the launch vehicle's overall performance. This allows for higher propellant mass fractions than would be possible with conventional normal boiling point cryogenic propellants, considering the normal boiling point of LO₂ and LH₂.

An LO₂ propellant densification unit was designed, built, and recently tested at the NASA Glenn Research Center. The steady-state demonstration and performance test series was conducted with the densifier to simulate LO₂ propellant tank loading, recirculation, and thermal stratification of the LO₂ loaded inside a flight-weight tank. The X-33-scale LO₂ densification unit as designed can process subcooled cryogen at a nominal rate of 30 lb/sec. The densifier subcools normal boiling point LO₂, thereby effectively lowering the temperature of the fluid from 168 °R to an outlet product temperature of 120 °R.



Testing has demonstrated the capability of the 30-lb_m/sec LO₂ propellant densification unit shown here, which is composed of a GN₂ cryogenic compressor, two heat exchangers in series, and an LO₂ pump. Test operations conducted with Glenn's densifier included oxygen loading, continuous production of 120 °R LO₂, fluid recirculation, and thermal stratification with the large-scale X-33 dual-lobe oxygen tank.

The continuous LO₂ densification production process utilizes two shell and spiral coil heat

exchangers in series. Both heat exchangers employ liquid nitrogen (LN_2) as the primary coolant on the shell side. The second heat exchanger is a high-efficiency, subatmospheric, LN_2 boiling bath operating at 117 °R that cools the inlet LO_2 propellant feed stream. A three-stage centrifugal compressor operating at cryogenic inlet conditions maintains the second heat exchanger bath vapor pressure below 3.0 psia. The LO_2 propellant densification unit hardware shown in the preceding photograph has a 30-lbm/sec production capability. The system is equipped with a cryogenic LO_2 recirculation pump for moving liquid from the propellant tank, into the densifier, and then back to the tank.

Densification performance tests started in October and were continued through early December 2000. Upon completion of Glenn's preliminary test matrix, which included densification checkout testing with LN_2 , a series of loading and densification tests with LO_2 were performed for the Lockheed Martin Michoud Space Systems group. The LO_2 densifier performance tests were conducted with a large-scale Lockheed tank designated the Structural Test Article (STA) (see the following photograph) integrated with the densification unit.



The Lockheed Martin propellant tank designated the Structural Test Article (STA) is a full-scale, flight-weight, prototype aluminum tank designed for the X-33 Reusable Launch Vehicle. The STA tank shown integrated with Glenn's LO_2 densification unit has a capacity of 20,000 gal of LO_2 . Buildup of the South Forty Test Facility at Glenn was completed in June 2000, and densifier performance testing was completed in December 2000.

Test operational and performance goals with the 30 lb_m/sec LO_2 densifier were successfully demonstrated during the course of the program. With the STA tank volume at around 20,000 gal, the initial loaded mass of normal boiling point LO_2 inside of the STA at the onset of the densification process was approximately 180,200 lb. Following completion of the 20 to 30 lb_m/sec densification flow testing, experimental results indicated that by the end of the process and based on an average bulk measured temperature of 123 °R, the final loaded mass of LO_2 was approximately 196,300 lb. This

additional loaded mass of 16,100 lb represented on average an 8.9-percent increase in onboard LO₂ propellant. Test results also confirmed the presence of thermally stratified oxygen layers inside the tank. These layers varied in the vertical direction from 122 °R for the colder, denser fluid at the bottom to 166 °R for the warmer, less dense LO₂ near the top outlet of the STA tank.

Glenn research engineers and employees from Sierra Lobo, Inc., supported South Forty Facility buildup and test operations during the developmental program. This propellant research and technology work completed at Glenn has advanced the state of the technology by demonstrating the feasibility of loading, producing, and maintaining densified LO₂ onboard an operational full-scale launch vehicle propellant tank.

Bibliography

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